Use of Data to Inform Risk Characterization and Management in Addressing Biofilm Problems

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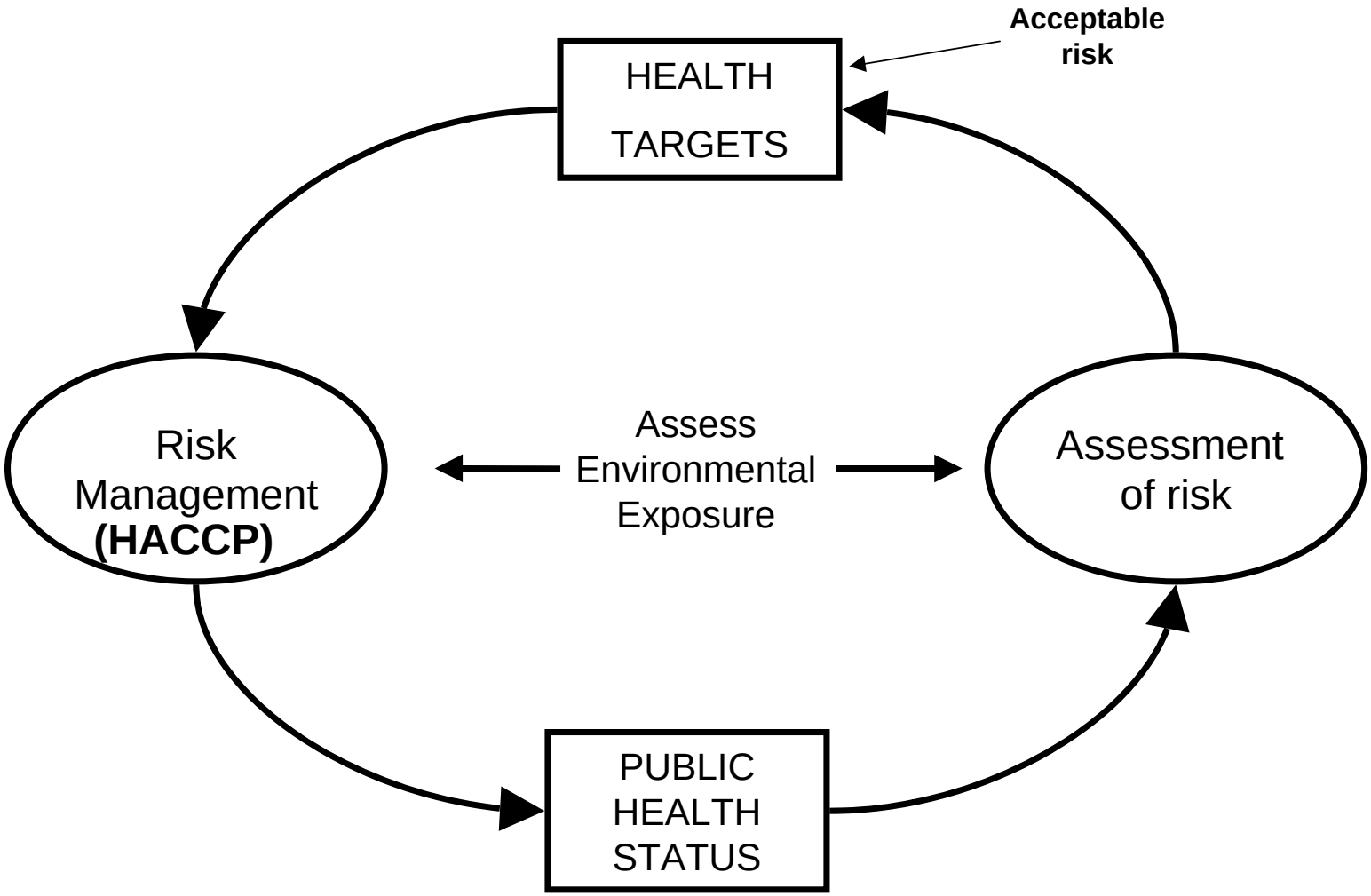
January 31, 2007

WHO risk-based approach to guidelines

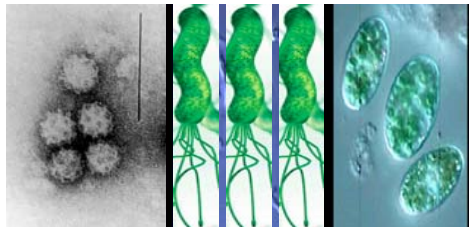
- Fewtrell & Bartram (2001) Guidelines, Standards and Health
  - www.who.int/water_sanitation_health/dwq/whoiwa/en/
- WHO 3rd Edition of Drinking Water Guidelines (2004)
  - http://www.who.int/water_sanitation_health/dwq/en/index.html

WHO Risk management approach

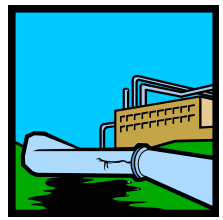


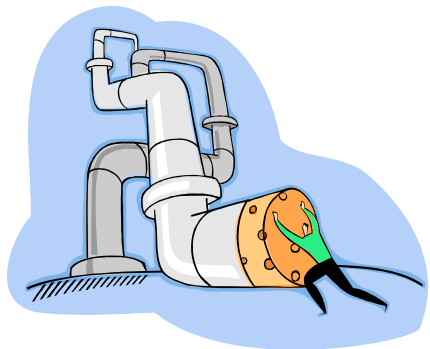
Fewtrell & Bartram (2003) IWA Publishing

Risk characterisation associated with distribution



- Requires information on:
  - Hazards (pathogens: fecal + non)
  - Hazardous events (breaks, backflow, X-connection, sloughing, etc.)
  - Hazard doses (conc. X vol.)
  - Dose-response (probability of illness)





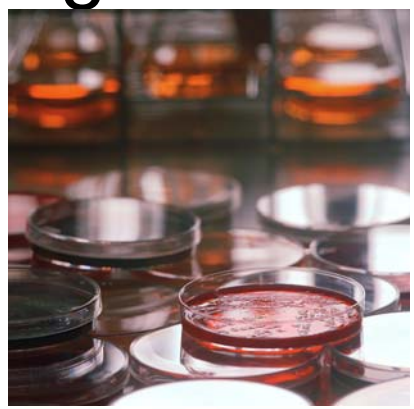
Risk estimates (inf. person^{-1}.y^{-1}) for simulated distribution intrusion event (MicroRisk Project)

Simulation	Avg.	95%ile	99%ile
Baseline (*Campylobacter* spp.)	4.9 10^{-8}	1.8 10^{-7}	1.310^{-6}
Baseline + Event (Acute) Infiltration of *E. coli* PDF T(0.5,1,10); Ratio of *E. coli : Campylobacter* = 1000; Probability of being affected = 0.00031 person^{-1}.d^{-1}. Duration of Event = 3 days	1.8 10^{-5}	6.5 10^{-5}	**4.8 10^{-4}**

Number in bold above Dutch benchmark risk of 10^{-4}.person^{-1}.year^{-1}

Points covered

1. Criteria for identifying a significant biofilm problem
2. Concerns that make biofilms a problem & some aspects for our advantage
3. Possible strategies for mitigating the biofilm problem



1. Criteria for identifying a significant biofilm problem

- Traditional - increase in:
  - HPCs
  - TCs
  - dirty water
  - taste & odor
  - loss of chlorine residual
    - Other use of SCADA data

Each significant if lack of compliance or complaints

Growth of coliforms in biofilms – may not be a health issue

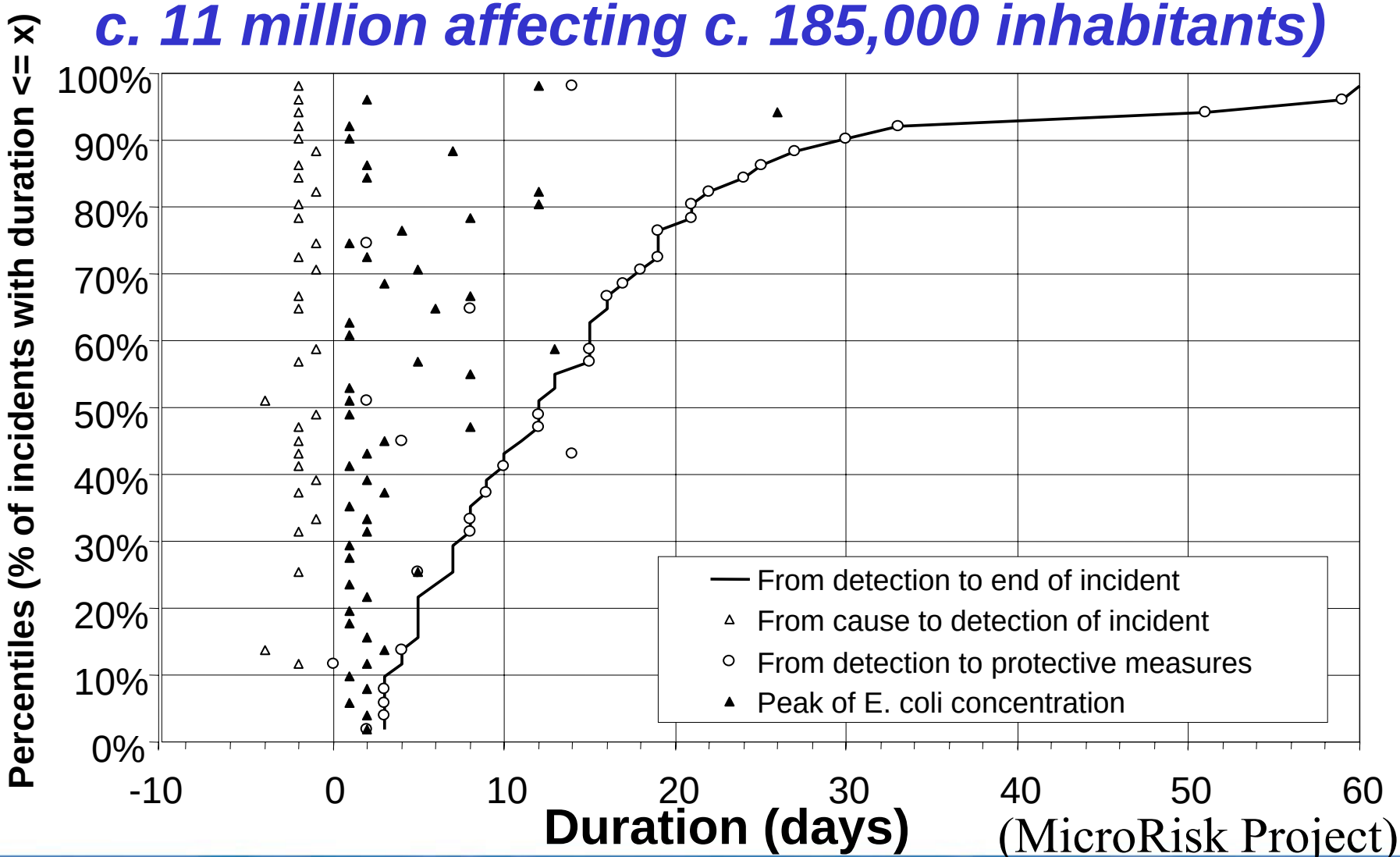
- Various coliforms are known to grow in pipe biofilms
  - Incl. *Citrobacter*, *Enterbacter*, *Klebsiella*
  - Latter include fecal coliform members
  - Hence importance of using *E. coli* or enterococci as the fecal indicator in follow-ups
- Some 3-8 % of systems have MCL non-acute violations but only 10% of these have acute violations (*E. coli* presence)

But how to separate growth from an intrusion event …

Fecal intrusion event: Investigation of taste issues 3rd Dec

Date (2001)	Homes Sampled (100mL)	No of samples containing indicator bacteria & sampled (max concentration CFU/100mL)			
		Coli37	Coli44	SSRC	FS
Dec. 4	2	**2** of 2 (19)	-	-	-
Dec. 5	12	**9** of 12 (13)	**8** of 12 (5)	**1** of 2 (4)	**2** of 12 (4)
Dec. 6	28	**8** of 28 (14)	**5** of 27 (9)	**8** of 22 (5)	**2** of 22 (3)
Dec. 7	19	0 of 19	0 of 19	0 of 19	0 of 19
Dec. 8	7	0 of 7	0 of 7	0 of 7	0 of 7
Dec. 9	21	0 of 21	0 of 21	**1** of 21 (1)	0 of 21
Dec. 10	23	0 of 23	0 of 23	0 of 21	0 of 23
Dec. 11	5	0 of 5	0 of 5	0 of 5	0 of 5
Dec. 12	12	0 of 12	0 of 12	**1** of 12 (1)	0 of 12
Dec. 13	6	0 of 6	0 of 6	0 of 6	0 of 6
Dec. 14	10	0 of 10	0 of 10	0 of 10	0 of 10
Dec. 15	13	0 of 13	0 of 13	0 of 13	0 of 13
Total	**158**	**17 of 156**	**13 of 155**	**11 of 138**	**4 of 150**

Duration of 50 fecal contamination incidents (Netherlands: 1994-2003 by 7 companies supplying c. 11 million affecting c. 185,000 inhabitants)



(MicroRisk Project)

Interpreting persistent non-acute TCR MCL violations

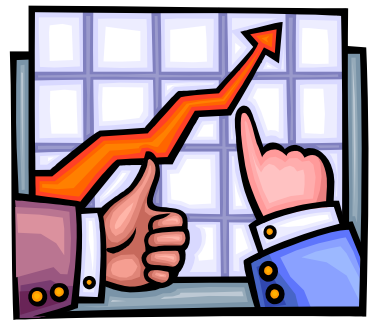
- In the absence of *E. coli*
  - Generally considered a non-health issue (from fecal pathogens)
  - However, if moderate chlorine residuals, fecal pathogens could still be infectious & *E. coli* non-culturable
  - Quick PCR test for *E. coli, Clostridium perfringens* (spores) or other persistent fecal marker could resolve this dilemma

High TC & no E. coli *– what about opportunistic pathogens?*

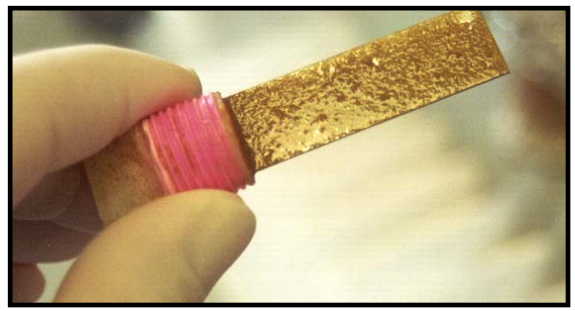
- This is the real question – for which there is no strong evidence of health effects, but no serious study either!
- No science to suggest that TC are a good index of opportunistic pathogens
- Rather just one of a group of heterotrophic bacteria that may grow in biofilms

Emerging criteria to ID biofilm problems (control charting at CCPs)

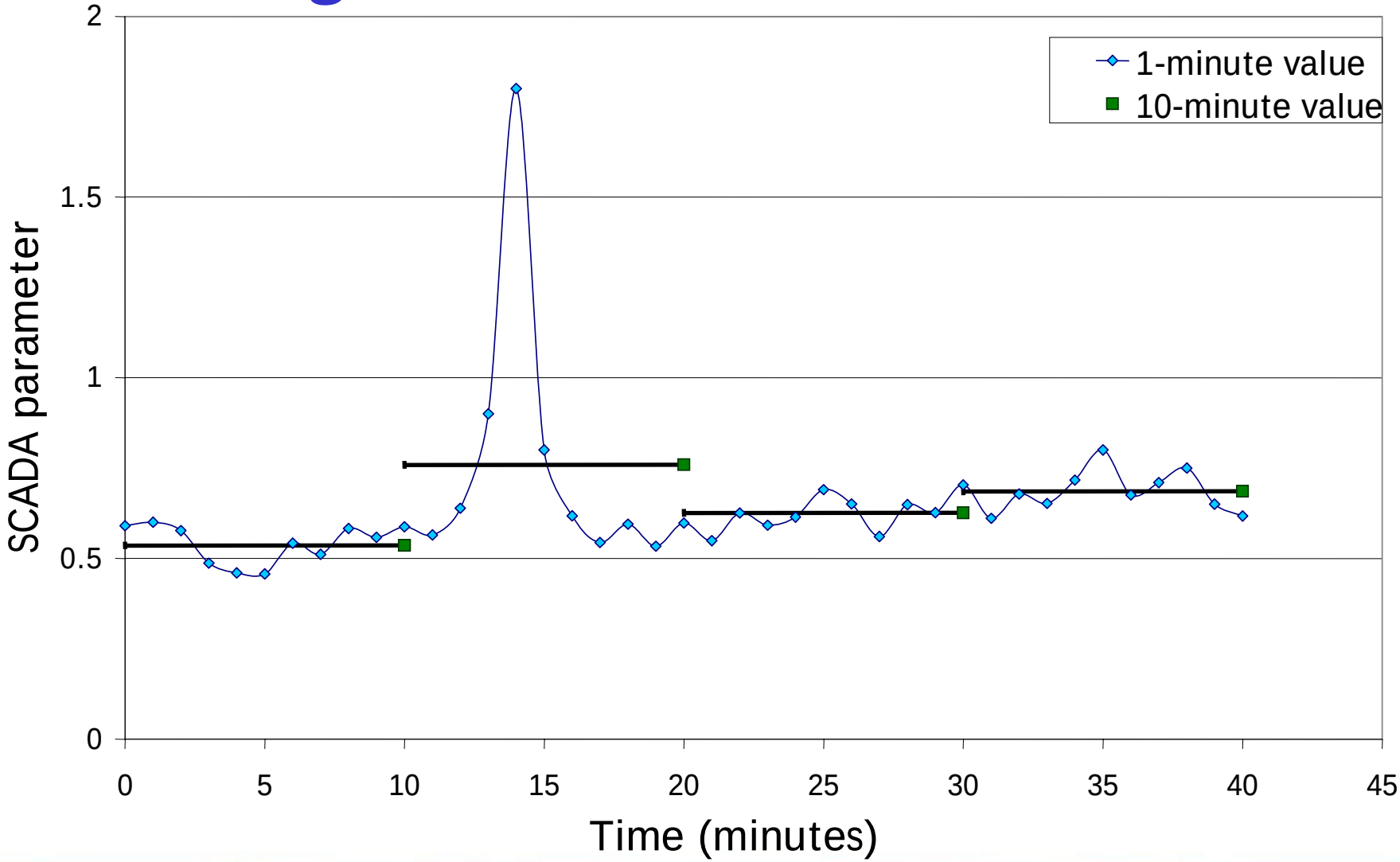
- On-line measurements that trend over critical limits, e.g.
  - Chlorine residual loss
  - Nitrification (nitrite)
  - ATP, TOC or other biomass measures



- Biofilm coupon assessment
  - In-pipe, annular reactors or loops off-pipe
    - ATP, TOC or other biomass measures
    - Rapid community ‘fingerprinting’

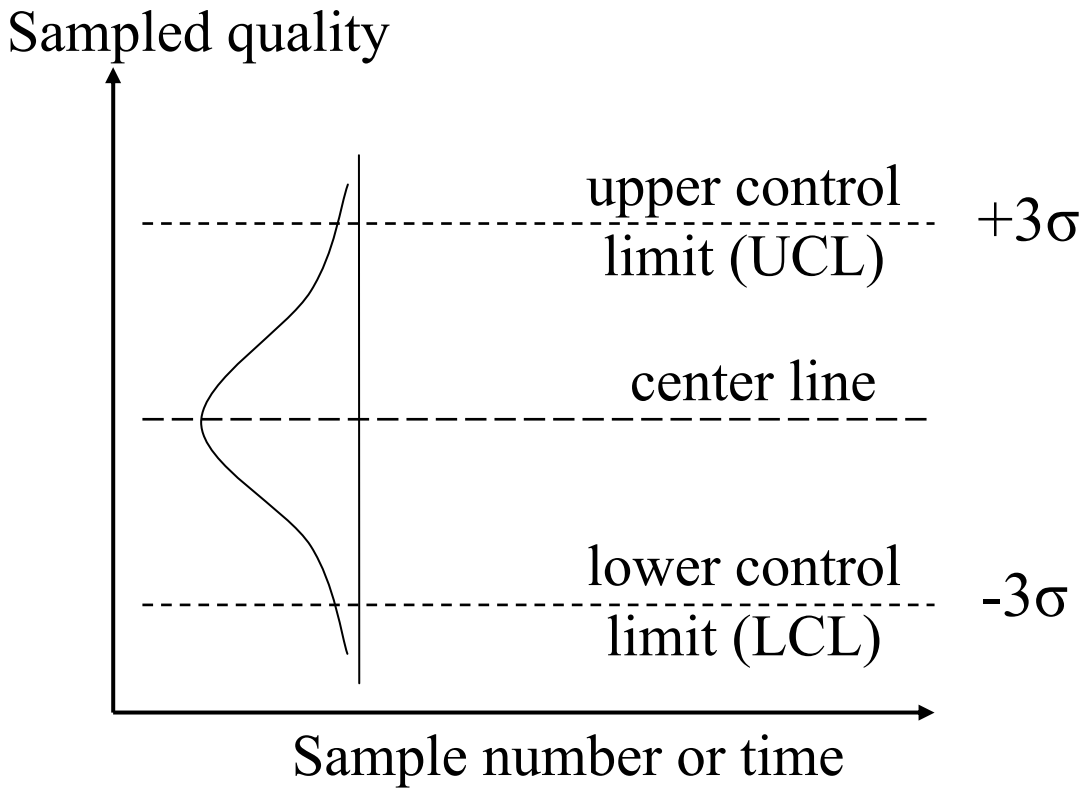


Identifying a hazardous event: e.g. 1 & 10 min SCADA data



Basis of control charting & Change point analysis

- Change point analysis used to detect slight changes missed by control charts
  - Cumulative Sum Control Charting (CUSUM)



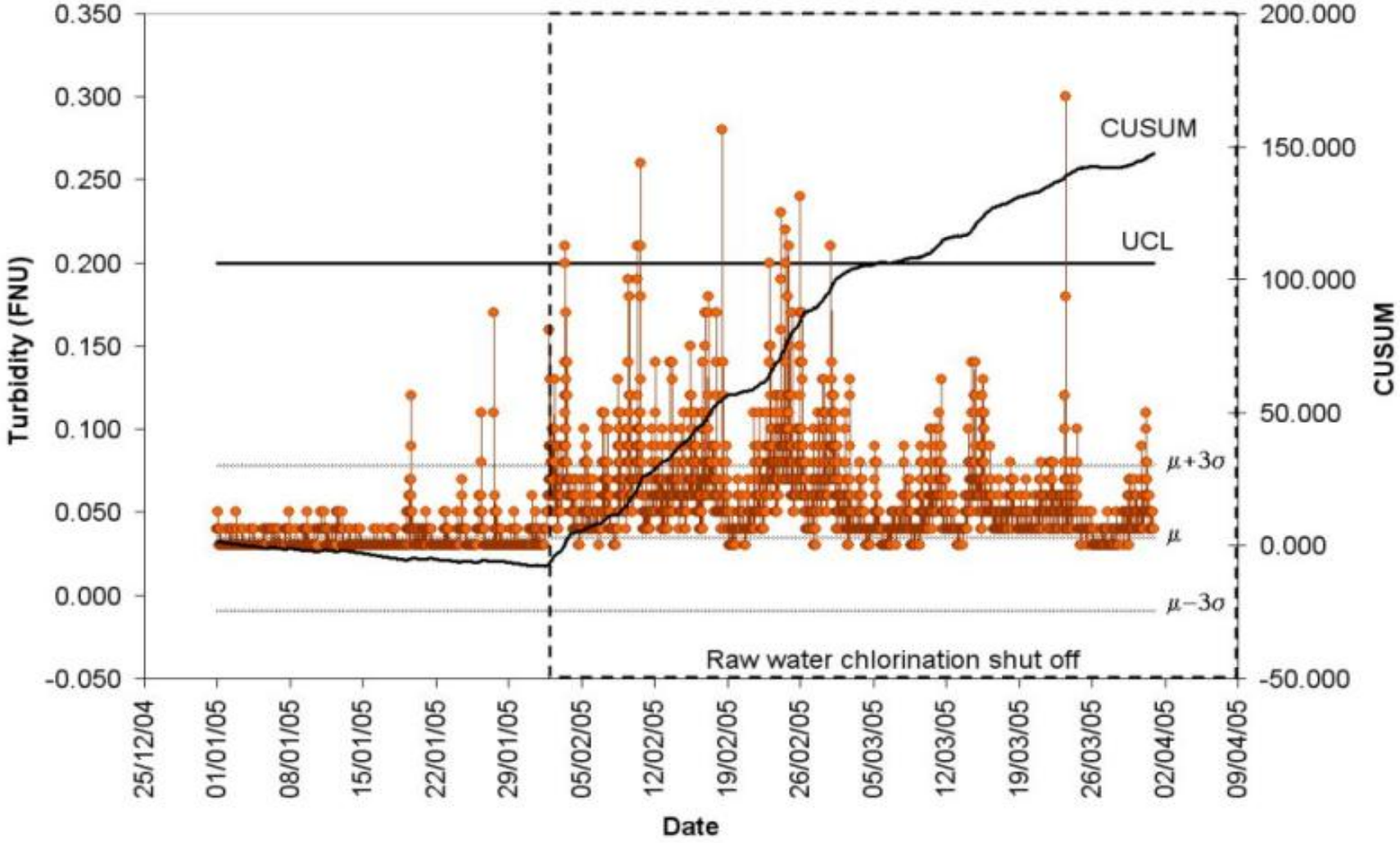
CUSUM charts

- The simplest CUSUM charts are constructed from a cumulative sum (S_n) based on the data:

$$S_n = S_{n-1} + (X_n - \overline{X})$$

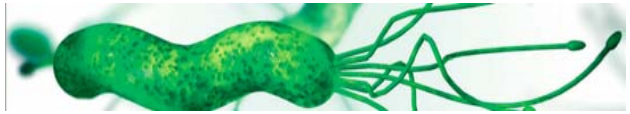
  - n is the total number of data points, X_n the data point, and $\overline{X}$ the arithmetic mean of the data points
- A CUSUM chart is interpreted as follows:
  - An upward slope indicates a period with values above average
  - A downward slope indicated a period with values below average
  - A sudden change in direction indicates a shift or change in the average
  - If the chart follows a straight path this indicates a period where the average did not change

Filtrate water turbidity SCADA with CUSUM and UCL

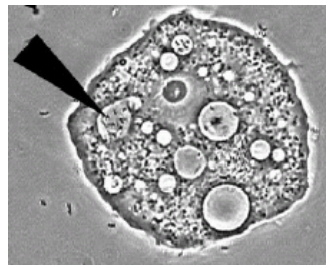


2. Concerns that make biofilms a problem

- Biofilms sequester fecal pathogens and allow the growth of opportunistic pathogens



Water-based bacterial pathogens



- Various *Legionella* strains
- *Mycobacterium avium, M. ulcerans*
- *Burkholderia pseudomallei*
- *Helicobacter pylori*
- *Aeromonas* & *Vibrio* spp.
- *Campylobacter* spp.?

- All grow associated with amoeba in biofilms & may be active but non-culturable

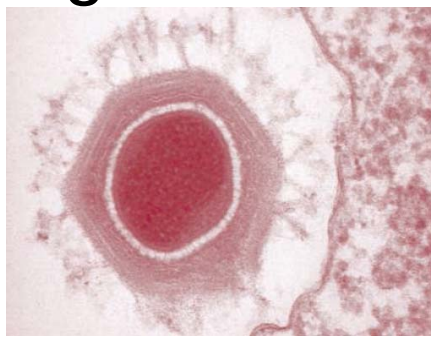
Pathogens also protected in biofilm ecosystems

- Biofilm slime ‘mops-up’ chlorine disinfectants & pathogens
- Acanthamoebae cysts remained viable
  - after treatment with 100 mg/L chlorine (free and combined) for 10 min, as well as
  - 80°C for 10 min – containing viable legionellae
- Implying that conventional hyper-disinfection or 80°C heating may be insufficient for long-term control of Acanthamoebae-bound Legionellae in water distribution systems

Storey *et al.* (2005) Scand. J. Infect. Dis. 36(9):656-662

And it gets worse!

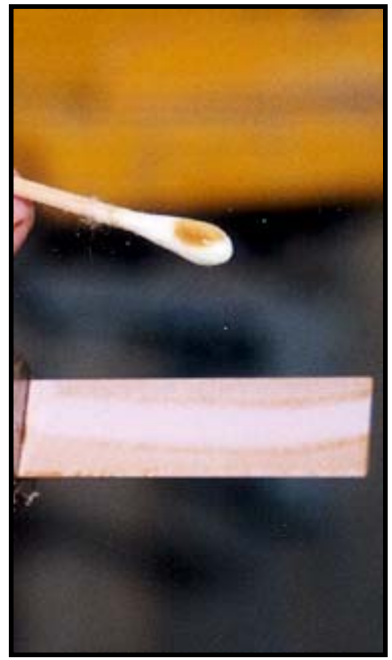
- *Acanthamoeba polyphaga* Mimivirus largest known DNA virus
- The word "girus" used to recognize the intermediate status of these giant DNA viruses
  - genome complexity which is closer to small parasitic prokaryotes than to regular viruses[1]
- Possibly > legionellae in causing community & nosocomal pneumonia[2]



750 nm dia

[1]Claverie *et al*. (2006) Virus Res.117(1):133-44
[2]La Scola *et al*. (2005) Emerg. Inf. Dis. 11(3):499-52
[2]Berger *et al*. (2006) Emerg. Inf. Dis. 12(2):248-55

Unintended disinfection effects



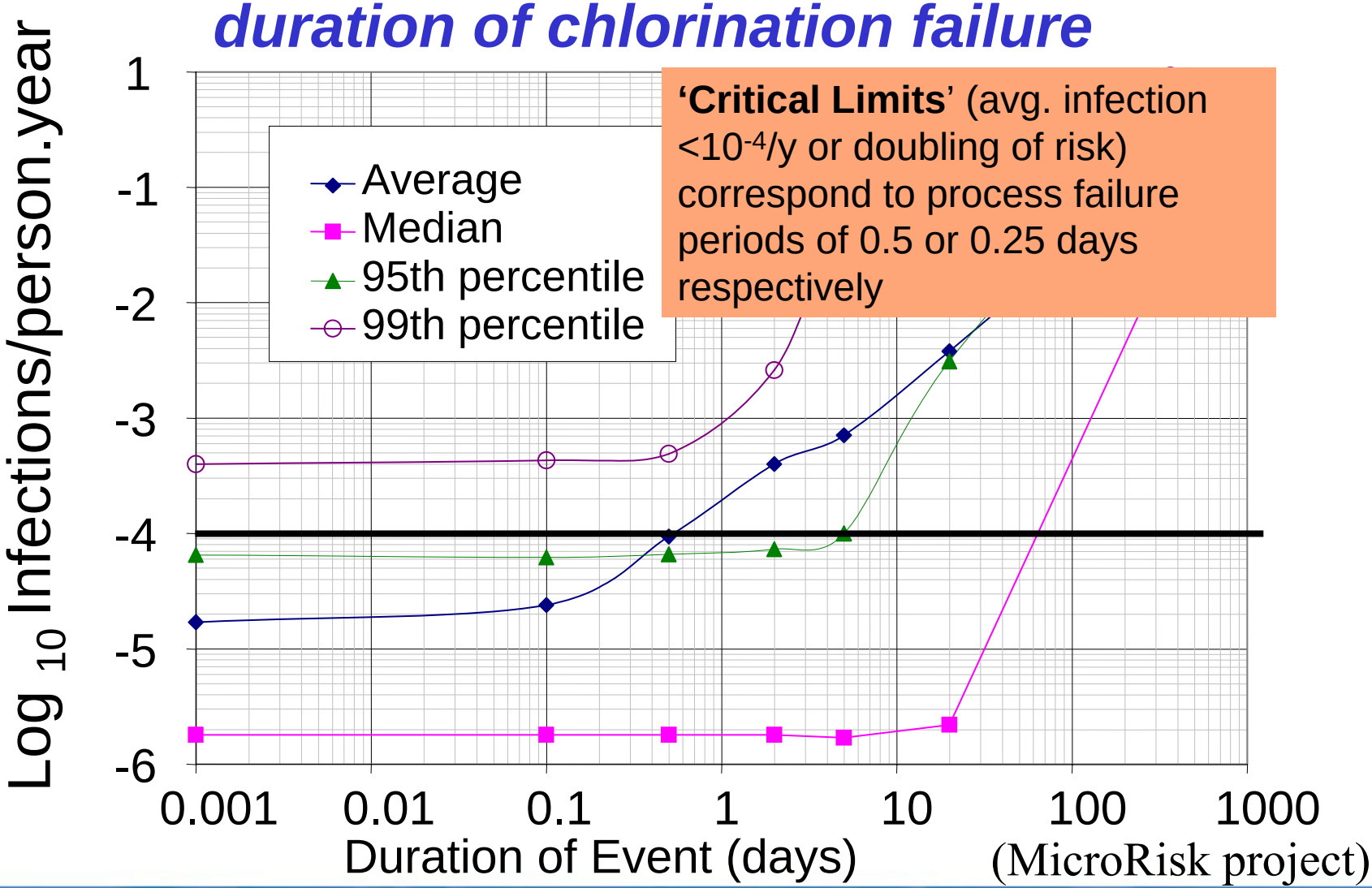
- Disinfection stresses cells, producing viable but non-culturable bacteria on selective media (= false negatives)
  - Yet would be PCR-positive (false positives)
- Hence, a molecular method or a chemical / chlorine-resistant fecal microbe could be used to indicate a contamination/biofilm event
  - e.g. on-line PCR, loss of chlorine residual, fecal sterol, change in NH_3 or clostridial spore assay

Whereas biofilms provide a history of contamination

- Because of their sequestering nature, biofilms are a good integrator of passed contamination
- Hence, biofilms may provide a preferable target to monitor than water – more representative, particularly for small systems with infrequent sampling

Short-term events are important

Campylobacter annualised infection risk vs duration of chlorination failure



'Critical Limits' (avg. infection $<10^{-4}$/y or doubling of risk) correspond to process failure periods of 0.5 or 0.25 days respectively

3. Possible strategies for mitigating the biofilm problem

- Once established, biofilms can readily re-immerge as a problem
  - As shown for *Legionella* in buildings and nitrification in chloraminated systems
- Control of biofilms means control of the factors for biofilm growth:
  - Temperature, C, N, P
  - But even very low C, N or P can yield problems in warm waters
  - Disinfection ± (e.g. monochloramine for *Legionella*, but may increase Mycobacteria)
  - **Selection of beneficial biofilm members requires community/ecological studies**

Hence, do not let biofilms establish in the first place

- Regular mains cleaning – preventative
  - Reduce dead ends and stagnant water zones
- But if biofilms reach the ‘pain threshold’:
  - Change disinfectant (however » dirty water)
  - Mains flushing/pigging
  - Do not replace with iron piping

International best management practice

- **WHO/NHMRC**: Neither HPC nor TC's promoted as fecal indicators, but may indicate possible biofilm problems (primarily indicators of water treatment disinfection efficacy)
- **Water safety plans used**: in distribution meaning focus on-line for **changes** in chlorine residuals, NH_3, TDS, turbidity or pressure

What is needed

- Inclusion of biofilm assessment as a key component for distribution system management, but reliant on:
  - New knowledge on ecology of fecal and non-fecal pathogens in pipe biofilms
    - Health significance still a major data gap
  - Sanitary survey and on-line control of hazardous events more important than sampling and culture-based monitoring

Acknowledgments & Disclaimer

- I would like to acknowledge the input of many UNSW students and colleagues who have worked with me on distribution systems & HACCP

- This presentation does not necessarily reflect official Agency policy